TROPICAL FOREST RESTORATION EXPERIENCES

D. Lamb, I. Siddique and **P.D. Erskine**
School of Integrative Biology, The University of Queensland, Australia

V. Lex Engel,
Agricultural Sciences Faculty, São Paulo State University (UNESP), Brazil

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Summary

Interest in the restoration of tropical forests has gathered momentum in recent years because of the continuing loss of goods and services from forests and the increasing areas of degraded and abandoned forest lands. Some of the diverse approaches to overcoming this degradation in tropical landscapes are illustrated using case studies from a range of countries. These studies demonstrate how unique socio-cultural conditions determine which forest restoration methods are used and highlight the costs, biodiversity gains and improvements in human well-being of these approaches. On a broader scale, issues of how to measure the success of forest restoration efforts are examined, as are some of the applications of the different approaches to landscape forest restoration.

1. Introduction

The loss of the world's tropical forests during the twentieth century has been one of the most dramatic global ecological changes caused by human activities. Not only has the amount of forest lost been large but the rate at which it has been lost has been unprecedented. The causes of the current tropical forest loss have been widely debated and vary from region to region. The more obvious factors are shifting cultivation or permanent conversion to agricultural use, harvesting of fuelwood and charcoal, unregulated logging, expansion of urban and industrial areas and, in drier areas, overgrazing and fodder collection (Shand 1997). However, the more fundamental underlying causes include rural poverty, inequitable land tenures, or inadequate government regulatory mechanisms (Schwartzman 1992). Any program aimed at overcoming degradation will necessarily have to keep these factors in mind if it is to be successful.

Deforestation has led to a loss of habitats and a loss of biodiversity—but also a loss of the goods and services upon which many rural people depend. Indeed, hundreds of millions of people throughout the tropics have been deriving goods such as foods, fodder, medicines, fuelwood and building supplies from forests. But most rural communities will have also benefited from the so-called ecological services that forests provide. These include functions such as protecting hill slopes from erosion, carbon sequestration and maintaining catchment water quality for human consumption. The supply of a wide range of such goods and services disappear when the forests are removed. In some places deforestation has led to increased agricultural cropland and may have been largely beneficial to rural communities. However, in many cases forest conversion to agriculture has benefited only small sections of rural communities, while it disadvantaged directly and/or indirectly the majority of others within the same region (Schwartzman 1992). Furthermore, economic benefits are short-lived where the established land use system does not sustain productivity, as is the case on the widespread strongly weathered tropical soils.

In some cases these degraded sites will recover unaided. This may occur if soil fertility is retained and if native species remain at or near the site and are able to recolonise it. But natural recovery does not always occur. Limitations to forest recovery vary drastically among sites and commonly include: fire, herbivore damage, shortage of propagules of native forest species, and competition with invasive or persistent plants delaying secondary succession, as well as deterioration in soil structural, hydrological and biogeochemical properties and processes.

There are a variety of approaches to overcoming degradation. A common approach is to simply attempt to maximize the commercial productivity of the site. This might be done using cash crops or commercial timber plantations. These forms of revegetation or reforestation usually have only limited success in re-establishing habitats or biodiversity.

Another approach aims at restoring the original ecosystems and the biodiversity these contained. This approach is referred to here as restoration (see Glossary).

A third group of approaches recognize that restoration is difficult to carry out if there are no accompanying benefits for rural populations nearby. These approaches therefore seek to improve commercial productivity and, at the same time, foster the recovery of at least some of the original biodiversity. These approaches will be referred to here as rehabilitation.

Restoration and rehabilitation have in common the fact they seek to restore key ecological functions by increasing the diversity of habitats and species once present (Engel & Parrotta, in Kageyama et al. 2003). These functional ecosystem processes and properties range from productivity and diversity through biogeochemical and hydrological cycles to plant-animal-microbe-soil interactions such as plant pollination, seed dispersal, soil animal ecosystem engineers, or microbial root symbioses.

2. Knowledge about Key Processes

One key constraint on achieving any kind of reforestation is that knowledge of the autecology of the large numbers of forest species found in most tropical forests and their silviculture is usually poor. This includes timber species that might once have fetched high prices when they were logged from natural forests. But for many species it may be difficult to specify when seed is likely to be available, how seed might be stored and how to germinate seed and raise large numbers of seedlings to meet a specified planting date. Of course many degraded sites will not now be suitable for many of these indigenous species anyway because environmental condition have changed so much. For example, topsoil has been lost, soils have become compacted and many sites available for reforestation are now fully exposed to the sun.

On the other hand, the general pattern of forest successional recovery after a disturbance is reasonably well understood. When natural forests are substantially cleared, the successional pathway often follows a reasonably well-known sequence. If the disturbance removes tree cover, but undisturbed forest is not too distant, the earliest plant colonists usually include grasses and forbs, as well as woody “pioneers”. These are fast-growing but short-lived shrubs and trees with widely dispersed seed (generally also stored in the dormant soil seed bank). Well-known examples are *Macaranga* in Asia and *Cecropia* in tropical America. Once established in sufficient densities, they provide a canopy cover that excludes aggressive species such as grasses but allow other, more slowly establishing species to colonize the site.

These later colonists include shrubs and herbs as well as longer-lived trees. A variety of species with different functional properties may be present in this mid- to late-successional group. Particularly early- and mid-successional trees tend to include many species which acquire nutrients from sources not accessible to most other species. Some may be nitrogen fixers or efficient mobilizers of sorbed soil phosphorus. Others may be deep-rooted plants able to reach nutrients accumulated in clay-rich subsoils in old tropical soils as a result of leaching during disturbance. Others might be especially efficient in retaining surface soils and preventing erosion by dense surface rooting and high rates of litter production. These various species change the site conditions and collectively facilitate the colonization of other more site-demanding species that, otherwise, would not have been able to regenerate at the site.

These changes in plant species composition and hence in the ecological processes operating within the community also occur in the animal populations. Some species are generalists like the plant pioneers and can tolerate the exposed conditions prevalent after a disturbance has removed the tree canopy cover. Some generalist birds, for example, may help bring plant seed into the new site through their droppings. However, as the forest height and structural complexity increases over time, additional animal species are able to find unoccupied habitat niches and so colonize the site. These, too, affect ecological processes and functioning because they influence pollination, seed dispersal, as well as herbivory, and may interact with other ecological functions (see Table 1).

Type of restoration	**Location**	**Biodiversity gain**	**Improvement in human well-being**	**Direct treatment costs**
Passive restoration	Tanzania	High	Direct benefits	Nil
	Puerto Rico	High	Indirect benefits	Nil
Direct seeding	Australia	Initially low	Indirect benefits	Low
	Laos	Initially low	Indirect benefits	Low
	Brazil (SE)	High	Indirect benefits	Moderate
Monoculture plantations	Vietnam	Low	Moderate	Moderate
	Australia	Sometimes high	Moderate-high	Moderate
Under-plantings	Burma	Moderate	Moderate-high	Moderate
	Vietnam	Moderate	Moderate-high	Moderate
Mixed species plantations	Brazil (SE)	High	Moderate	High
	Brazil (Central)	High	Indirect benefits	High

Table 1. Tropical forest restoration case studies.

A key question arising from this is whether it is necessary to replicate this successional sequence when restoring a forest? Or, is it possible to accelerate the sequence or by-pass certain stages? While we still do not know the “assembly rules” necessary to restore a tropical forest, experience emerging from many field trials suggests it is not necessary to exactly simulate natural successions in order to restore degraded sites. Rather, some stages such as the pioneer dominated stage can be leap-frogged and many species normally found in later successional stages can often be introduced earlier. Thus, it is possible to optimize and accelerate restoration, for instance by utilizing functional complementarities between cover crops, shrubs and trees (Buckles et al. 1998). Exactly how such a process is managed depends on the objective of reforestation.

3. Using differing approaches under different circumstances

Different managers will always have different objectives but the most appropriate approach to use to overcome degradation at a particular site will necessarily depend on ecological, economic and social factors. Ecological factors such as the extent of degradation and the amount of forest remaining nearby will determine whether or not the forest will recover relatively quickly without further intervention. The conservation status of species in the area might also determine what type of reforestation is needed to ensure these species are able to persist. However, the type of intervention will also depend on economic factors. For example, economic factors will determine the extent of funds and other resources available to overcome degradation.

These factors will also determine whether landowners can take a long-term view and undertake restoration or rehabilitation or whether they must react to short-term imperatives of food production or the production of market goods such as timber. For example, a human population may be forced to begin harvesting firewood or some other valued resource from a regenerating forest if the opportunity cost of not doing so becomes too high. Economic issues will also determine whether degradation can be dealt with in single large scale operations or in many small-scale operations spread over a number of years. Among the social factors influencing the way in which degradation is addressed, perhaps the key one is whether land users have full land tenure or not. In most circumstances it is difficult for any form of reforestation to take place if the local stakeholders have no secure land access.

4. Case Studies

Despite the uncertainties about methodologies and the great differences in objectives, there are a number of examples where degraded lands have been restored in various ways. Some of these are outlined in the case studies below. These case studies (see Table 1 and below) vary from largely passive operations where there was minimal intervention to more expensive and detailed programs where the successional development was much more directed. What makes these case studies especially interesting is that they reflect the outcome of the interaction between ecological and socio-economic systems.

4.1. Tanzania: natural regeneration following a land use policy change

The open woodlands in the Shinyangan region of Tanzania cover a large area and are heavily used by traditional agro-pastoralists. The population of the area is relatively high (42 persons per km^2). The region has a rainfall of 600-800 mm but is subject to frequent droughts. In pre-colonial times families and clans developed a system of controlled grazing and enclosures to keep fodder available for their animals during drier periods. These management systems depended on rules maintained by guards and community assemblies. This meant that pasture was preserved and there was a significant pool of biodiversity contained in the woodlands distributed across the landscape. These woodlands contained many resources used by rural communities such as foods and medicinal plants.

This system was changed during the colonial period and in the early years of independence. In the 1920s many woodlands were cleared to eradicate tsetse fly and, later, to establish cash crops such as cotton, tobacco and rice. This accelerated soil erosion and reduced land available to families and clans for grazing. Following the end of the colonial period new government policy changes led to the grouping of communities into villages to make it easier to provide social services to people. However this caused a breakdown of the traditional management systems leading to overgrazing, especially in the vicinity of the new villages. Increased populations also led to greater demands for timber and other forest products such as fruits, nuts and berries which caused over-harvesting in the remaining woodlands that were no longer subject to traditional harvesting regulations.

A policy reversal took place in the 1980s leading to a break up of the government village system and the re-establishment of the traditional management approaches including the recreation of the system of enclosures. This fostered a massive increase in natural regeneration of woody plants. In 1986 there were 600 ha in exclosures but by 2002 there were 250 000 ha. Traditional community management systems are being redeveloped and supported by government agencies. The government has also begun granting more permanent forms of land tenure.

It is impossible to know if all the former species have regenerated at the degraded sites. However, there is no doubt that significant reforestation has taken place, new habitats have been created and that biological diversity has increased. For example, some surveys have found up to 23 tree species in an area of only 0.5 ha. What is clear is that the forest regeneration has produced significant benefits for the human populations. Productive pastures are being re-established and the tree regeneration is helping to reduce erosion as well as provide new resources such as forage and browse for livestock, foods, medicines and timber.

Lessons: Even degraded lands can sometimes retain considerable amounts of biodiversity. Under the right conditions, this can regenerate and allow ecosystem recovery. Restoration was accomplished by a change in government policy and did not require large financial investments. The policy change included allowing land ownership to return to traditional owners and the restoration of tradition management practices.

Source: Barrow, E. and W. Mlenge. 2003. Trees as key to pastoralist risk management in semi-arid landscapes in Shinyanga, Tanzania and Turkana, Kenya. Presented at International Conference on Rural Livelihoods, Forest and Biodiversity. Bonn, Germany. Center for International Forest Research.

4.2. Puerto Rico: natural regeneration after a demographic change

At the commencement of the twentieth century more than 90% of the land area of Puerto Rico had been cleared for agriculture (crops such as sugar cane and coffee as well as pastures) and natural forest was restricted to smaller areas mostly on the steeper mountain areas. After 1940 the population shifted from the country to the cities as agriculture became less profitable. Many former farms were abandoned and have now been occupied by secondary forest. Soil fertility had not been lost during farming and, in the absence of fire, natural forest regeneration has been relatively rapid. This has largely developed from new colonists reaching the site rather than from species persisting at the site (e.g. in soil seed banks) during farming. A relatively small group of species commonly formed the initial cover of woody plants at recently abandoned farms. All were species that produced large numbers of seed and were easily dispersed by wind or animals such as birds or bats. Once established, their presence created new habitats and facilitated the colonization of a much wider range of other species. After 35 to 40 years the tree density, basal area and species richness in the regenerating forest was similar to that in older (>80 years) forests thought to be representative of the original forests on the island.

Thus the average basal area in 35 to 40 year old sites was 30 m^2 per ha in comparison to 39 m^2 per ha in the oldest forests. There were 23 species of woody species (with DBH >5cm) in a 200 m^2 plot in 35-40 year regrowth and a similar number in the older sites. However, the composition of these regrowth areas was quite different to the older forests and many exotic species were present amongst the colonists. If managers wished to foster the development of a forest containing more native species representative of mature successional stages then some kind of enrichment planting would be necessary. These species are present across the landscape but their slow rates of dispersal are limiting the extent to which they are represented in the new secondary forests.

Lessons: Recovery of these forests took place because of demographic changes and not because of deliberate technical interventions. This case study demonstrates that the recovery of forest structure can be rapid if soil fertility is maintained and if intact forest remains nearby. The rate at which the original species diversity recovers, however, may be slow since most of the new colonists are the most easily dispersed species. These are only a sub-set of the island flora.

Source: Aide, T.M., Zimmerman, J.K., Pascarella, J.B.,Rivera, L. and Marcano-Vega H. 2000. Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. Restoration Ecology 8:328

4.3. Australia: direct seeding of rainforest species in the Wet Tropics

When most of the rainforest areas in north Queensland of Australia were declared the Wet Tropics World Heritage Area a number of programs were developed to recreate some of the rainforest systems which had been lost. The “Maximum Diversity Method” (Goosem and Tucker 1995) was the main technique used to restore rainforests in the region and this method required extensive site preparation, dense plantings of up to 80 local rainforest species and site management (weeding and the replacement of any dead seedlings) for three years. This intensive method was relatively successful at recreating diverse forest systems but total costs were around US$20 000 per hectare. Alternatives, such as direct seeding of rainforest species, were seldom used because adequate methods had not been established.

For this reason an experimental system that included a range of species with different seed sizes and successional status, sowing methods, planting times and degrees of site maintenance was trialed across an altitudinal gradient. These trials showed the percentage of seedlings established from a given amount of seed could be low but that direct seeding was possible under certain circumstances. These are when it is carried out at higher altitudes (>800 m a.s.l.) where competition with weeds (particularly grasses) is low compared with that experienced at lower elevations, and where there are species with seed that is abundant and easily stored. Sowing should be conducted in either the early or mid-wet season after weeds have been eradicated by herbicides when there is adequate rainfall following sowing.

Under these circumstances, large seeded species (e.g. *Aleurites rockinghamensis* and *Castanospermum australe*) that have adequate seed reserves germinate and establish quickly, especially if seeds are buried rather than broadcast sown. In fact all species established best when seeds were buried and had sufficient contact with soil layers. Seed broadcast to undisturbed soil surfaces resulted in significantly poorer establishment rates of seedlings than treatments involving seed burial. Following a similar cost structure to that of organizations conducting rainforest restoration using seedlings it is estimated that it would cost around US$5000 per hectare to conduct direct seeding successfully in the Wet Tropics of Australia.

Lessons: It is possible to utilize direct seeding to restore forest habitats but the technique is only appropriate under certain prescribed conditions. The approach requires large numbers of seed and best results are usually found when large seeded species are sown into weed-free conditions and placed in intimate contact with the soil. Considerable local testing is probably required to utilize the technique more widely.

Source: Doust, S. (2005) Seed and Seedling Ecology in the Early Stages of Rainforest Restoration. PhD Thesis, The University of Queensland, Brisbane, Australia.

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Shand H. (1997). Forests. In Part II: Biodiversity for Food and Agriculture. Pages 53-65 in Human Nature: Agricultural Biodiversity and Farm-Based Food Security. Rural Advancement Foundation International (RAFI), Ottawa, Canada. FULLTEXT ONLINE: http://www.etcgroup.org/documents/other_human.pdf [This chapter compiles a global overview of the state of forest resources, genetic diversity and implications for livelihoods]

Biographical Sketches

David Lamb BForSc, PhD has extensive experience in tropical and subtropical forest biology, restoration ecology and conservation biology. He is an Associate Professor in the School of Integrative Biology at the University of Queensland and leader of the Tropical Forestry Group within UQ. Over the last 30 years David has worked in forestry and tropical forest restoration in Papua New Guinea, the Solomon Islands, Australia and Vietnam. He is Coordinator of the Working Group on Restoration of Degraded Sites for the International Union of Forest Research Organizations (IUFRO) and Leader of the Ecological Restoration Group for the International Union for the Conservation of Nature (IUCN).

Ilyas Siddique BSc (Hons) started his ecological restoration work in tropical forests in 1998 on participatory research and planning of natural resource management in Peruvian Amazonia with the Indigenous and Farmers' Agroforestry Coordinating Body of Peru.

He graduated with a BSc (Hons) in Tropical Environmental Science from the University of Aberdeen (Scotland) in 2001, from where he coordinated a research expedition to the Institute of Fundamental Studies in Sri Lanka on soil chemical fertility restoration in eroded tea lands by multi-species forest gardens. After two years of assisting teaching in biology, environmental science and soil science at the University of Aberdeen, he took on a PhD Scholarship from the University of Queensland (Australia) in 2003.

On an internship with the Woods Hole Research Center (Massachusetts) and under supervision of its Brazilian collaborating research institutions, Ilyas carried out fieldwork on woody plant responses to nutritional limitations in degraded pastures in eastern Amazonia. He completed the overseas component of his PhD at São Paulo State University on tree nutritional responses in mixed plantings of functionally contrasting composition on a degraded, phosphorus-poor soil in south-eastern Brazil. To conclude his PhD, Ilyas is currently conducting inter-linked field and glasshouse mesocosm experiments in Eastern Australia on inter-specific complementarity among tree nutritional responses to low N and P availability in mixed plantings on degraded soils.

During his most recent field visits to a forest research center in Vietnam and the University of the South Pacific in Samoa, Ilyas studied land use in relation to soil degradation, exotic species invasion, and primary succession on volcanic substrates. Besides his university curriculum and informal interaction with specialists in related fields, Ilyas has participated in more than forty workshops and training courses in science, natural resource management, social science, economics, indigenous knowledge, facilitation in participatory research, planning and education, and fund raising.

Peter Damian Erskine, BSc (Hons), PhD is a forest ecologist with experience in conservation, forest biology and forest rehabilitation in Australia, Papua New Guinea, Uganda and Vietnam. He is currently a research fellow with the Rainforest Co-operative Research Centre assessing best-practice methods to rehabilitate forests on degraded tropical lands. He has recently been involved in: ethnobotanical surveys in Bwindi Impenetrable National Park in Uganda; environmental and social impact assessments of logging operations in Papua New Guinea, and the development of a community-based strategy for forest rehabilitation in Yok Don National Park, Vietnam. He continues to be involved with a project investigating mixed species plantations of high-value trees for timber production and enhanced community services in Vietnam and Australia.

Vera Lex Engel MSc, PhD graduated in Forestry, obtained her MSc in Forest Science at the University of São Paulo (USP), and her PhD in Ecology at the State University of Campinas (UNICAMP), Brazil. Since 1989 she has been an Assistant Professor at São Paulo State University (UNESP), Faculty of Agronomic Sciences (FCA) at Botucatu, SP, Brazil. Within the Forestry degree program she is responsible for the subjects: Dendrology, Forest Ecology, Tropical Forestry and Forest Restoration. Her research areas are natural forest structure and dynamics, native tree species silviculture, agroforestry systems and forest restoration. Her scientific activities include, among others, the publication of 18 papers in scientific journals, 50 papers presented at national and international conferences, two books and two book chapters, besides the supervision of 43 scientific initiation research projects, 15 undergraduate dissertations, as well as 6 MSc and PhD students. Her administrative experience includes a position as Director of the Forest and Agriculture Research Foundation (FEPAF) from October 1999 to March 2001, as the Vice-head of the UNESP Department of Natural Resources (2004-2006) and as Coordinator of the Forestry degree program at UNESP. She is a member of IUFRO (International Union of Forest Research Organizations), Division I, Working Party P.17, Restoration of Tropical Forests, where she has acted as Deputy Coordinator (2000-2005).